Institute for
Sustainable Futures

Design, Architecture &
Building

Addressing Expanded Polystyrene Waste Through A Closed-Loop System Using Digital Technologies: University of Technology Sydney Pilot Study

PREPARED FOR:
City of Sydney

About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures. We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

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The UTS Faculty of Design, Architecture and Building (DAB) contributes to the transformation of urban life, contemporary design culture and the built environment through thier research, education and engagement with the professions.

For further information visit: www.uts.edu.au/about/faculty-design-architecture-and-building

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1 Executive Summary

Researchers from the Institute for Sustainable Futures (ISF), together with researchers and Masters of Design students from Design Architecture and Building (DAB) at the University of Technology Sydney (UTS) received a City of Sydney Innovation Grant to assess the feasibility of developing a closed-loop system for recycling Expanded Polystyrene (EPS) using digital technologies within UTS.

EPS packaging was selected as a target material due to the lack of effective collection and reprocessing systems currently in Australia. Owing to the low density of EPS, it is a challenge to handle and transport, takes up considerable space in landfill, and poses a significant litter problem. EPS also currently incurs high handling costs for local governments, relative to the low landfill disposal charges based on weight.

Finding reusable or recyclable packaging alternatives to EPS should be the first priority. However, for packaging applications for which there are no alternatives yet available, new, localised recycling mechanisms for EPS are still required.

Digital technologies, such as Additive Manufacturing (AM—commonly known as 3D printing) and Computer Numerical Control (CNC) machines, are emerging as promising mechanisms to transform problematic materials in new ways. They have been particularly useful in the context of local, decentralised recycling systems operated at a community scale. This project aimed to investigate whether these technologies can be utilised to develop a closed-loop system for EPS recycling UTS, in which material sourced from campus is recycled into products that can be utilised on campus.

This system could **reduce waste generation** by:

1. Providing a viable recycling mechanism and developing a new end-market for recycled EPS.
2. Reducing the need for new products made from virgin plastics within the UTS community.
3. Developing transferable skills within the UTS community for recycling problem wastes using digital technologies.
4. Educating the broader UTS community about problem waste recycling through various communication channels, such as recycled product labels, video and print media.
5. Potentially providing a means for organisations across the City to recycle EPS, if scale-up is feasible.
6. Developing design and digital technology skills to contribute to the development of markets for recycled EPS products in Australia.

Methodology

Our approach to assessing the feasibility of the proposed system broadly encompassed the following stages: 1) an investigation EPS flows at UTS; 2) consultation with UTS stakeholders regarding current EPS requirements and disposal practices and the most beneficial recycled EPS products to create; 3) experimentation to determine the potential uses and performance of EPS using digital technologies; 4) the creation of prototypes for recycled EPS products based on stakeholder feedback; 5) prototype evaluation based on a sustainability assessment framework and stakeholder requirements.

Key findings

In characterising the sources of EPS on campus, we identify **opportunities to replace EPS with more sustainable packaging** options, which should be prioritised over recycling mechanisms. In doing this, we highlight how certain systems of provisioning items, such as fresh food, replacing the functional properties of EPS packaging with other products has been challenging. To replace EPS in these cases will require a re-evaluation of broader systems of distribution and provisioning.

We found that it is feasible to recycle campus-sourced EPS into essential products, such as signage, trollies, and trays for use in the University. Such a system consequently has the capacity to **improve the environmental performance of existing buildings** across UTS. Once key considerations identified are addressed, we propose there is also potential to expand this closed-loop system to other organisations within the City of Sydney.

2 Project Aims and Scope

Project Aims

The aim of this project was to test the feasibility of a closed-loop system for recycling EPS within UTS using digital technologies.

Inclusions

1. Identify the primary sources of EPS on campus, and primary routes of disposal.
2. Test the utility of different digital technologies in recycling EPS into durable items.
3. Evaluate the potential environmental savings and impacts of creating a closed-loop system for recycling EPS using digital technologies on the UTS campus.
4. Evaluate the feasibility of developing markets for socially and physically durable recycled EPS products that will reduce the amount of EPS going to landfill, based on the development of product prototypes.
5. Assess the capacity to scale up this system, if feasible, to other organisations and buildings within the City of Sydney.

Exclusions

1. As this is a feasibility study, the production of finished products to be implemented within UTS is outside of the scope of this project.
2. Due to a lack of quantitative data collected by UTS, the detailing of precise figures for sources and disposal rates of EPS within UTS are not included this study. Rather, a qualitative evaluation based on extensive interviews and observations is included.

Project Outcomes and Goals

Table 1 details the key outcomes and goals developed for the project, and how we measured and verified them.

Table 1: project outcomes, performance measures and means of verification

Project outcome or goal	Performance measure	Means of verification
Improved knowledge of EPS flows on campus	Volumes collected and processed	Weight taken at collection points scheduled throughout project
Characterisation of potential EPS recovered products	Number of suitable product types identified	Confirmation of demand eg based on current sales data for replacement products
Rate of processing of extruding machines	Time/amount processed	Repot amount processed over given timeframe
Capacity of different digital technologies to contribute to EPS recycling	Qualitative assessment of different technologies for multiple processing tasks	Products produced through each of the relative technologies trialled

Characterisation of potential end-use market on campus	Demand per unit of EPS recovered product	Confirmation of demand
Mapping viable channels/stakeholders for growing new markets off campus	Demand per unit of EPS recovered product	Confirmation of demand

3 Background

3.1 Context: Expanded Polystyrene waste in Australia

EPS is a recyclable polymer that is primarily used in building and packaging applications. Estimated consumption in Australia is 71,000 tonnes, growing at a rate of 5% per annum, of this, only 3,000 tonnes of EPS reprocessed and used locally.[1]

EPS is classified as a 'problem waste', as it is challenging to recycle and efficiently transport, and secondary markets remain underdeveloped.[1] It's light weight also means that it is easily carried by the wind, often leading to environmental pollution. Due to these limitations, EPS recycling in Australia is currently difficult to access for organisations and individuals, with less than one collection point per-state. Of the material collected for recycling, the vast majority is exported for reprocessing, due to insufficient domestic demand. This model is problematic, as it relies on international recyclers and markets.

Due to increasing costs of processing, decreased demand for recycled plastics and tighter controls on material contamination (particularly in Chinese markets) EPS recycling in Australia is diminishing further. Cleanaway currently runs the only commercial EPS collection service for recycling in New South Wales that could be found. However, they are about to discontinue this service due to running costs and decreased demand for EPS with any contamination from other plastics. Previously, contamination rates of up to 10% would not affect sales, however lower contamination rates are now accepted. Interviews conducted for this project indicated that China's ban on contaminated plastics has consequently created an oversupply of recycled EPS, meaning that the best price for recycled EPS is currently $500/t, down from $1500/t.

Industries that utilise EPS

The 2016–17 Australian Plastics Recycling Survey reported that key industries that utilise EPS in Australia include construction (48%), municipal packaging (19.8%), and commercial and industrial packaging (17%).[2] NSW produces and consumes the most EPS in Australia (~26%).

Expanded Polystyrene Australia estimate 3,000 tonnes of EPS are recycled locally and 6,000 tonnes are exported for recycling export. The major use of recycled EPS in Australia is waffle pods for under slab construction of buildings, while minor uses have included synthetic timber (such as photo frames, fence posts and decorative architraves), extruded polystyrene (XPS) insulation sheeting, and lightweight concrete.[3]

3.2 Digital technologies and recycling: an innovative approach

This project tests the applicability of a range of new technologies for managing waste EPS through a closed-loop system, including the integrated sourcing of waste material, processing, design, manufacture, distribution and consumption of goods. The contemporary digital technologies selected, such as Additive Manufacturing (AM—commonly known as 3D printing) and Computer Numerical Control (CNC) machines, allow the rapid design, prototyping and manufacture of goods. Unlike technologies and processes associated with mass production, contemporary digital fabrication is suited to creating smaller runs of distinctive products that allow small to medium enterprises (SMEs) greater flexibility in experimenting to create innovative products. Exploration of digital fabrication technologies in the context of a closed-loop recycling system will be particularly useful for SMEs that are looking to incorporate sustainability imperatives alongside exploring innovative possibilities associated with new technologies, and small to medium scale 'activity centres' or 'hubs', which might reinvigorate manufacturing in inner Sydney. While the specific technologies and processes used in this project have applications at the extremes of the macro (industrial) and micro (domestic), small to medium scale applications and the community and business benefits they afford are less thoroughly explored.

4 Methodology

This project was based on the development of eight key overlapping stages, six of which make up this initial feasibility study:

1. An investigation EPS flows at UTS;
2. Consultation with UTS stakeholders regarding current EPS requirements and disposal practices;
3. Consultation with UTS stakeholders to determine the most beneficial recycled EPS products to create;
4. Experimentation to determine the potential uses and performance of EPS using digital technologies;
5. Prototypes created for recycled EPS products based on stakeholder feedback;
6. Evaluation of prototypes based on sustainability assessment framework and utility to stakeholders;

Stages following feasibility study:

7. Product re-design and re-evaluation based on further stakeholder engagement;
8. Engagement with other organisations in the City of Sydney regarding EPS use and disposal, and potential to adopt recycling system.

In the initial project plan we proposed to monitor changes in EPS flows on campus once the products were in circulation. This monitoring became a qualitative rather than a quantitative exercise for two reasons, 1) EPS is not adequately quantified (weighted or counted) at the majority of collection points on campus, meaning it was not possible to calculate flows, and 2) a percentage of EPS is privately brought into and taken from campus by individual staff and students.

5 Findings

This section provides an overview of the key findings from the research stages described above.

5.1 Expanded Polystyrene within UTS: system overview

Flows of EPS in and out of UTS were evaluated. Due to the limited commercial value of EPS in Australia, UTS has not implemented mechanisms to quantify EPS entering and exiting the University. The only quantification of EPS occurs at the point of collection for disposal. Based on collection figures form this point, UTS processes 2.03t/year, with an approximate value of $1,015 (based on the current market rate of $500 per tonne). The primary inputs and outputs of EPS across UTS are represented in Figure 1 below.

Figure 1: Inputs and outputs of EPS across UTS

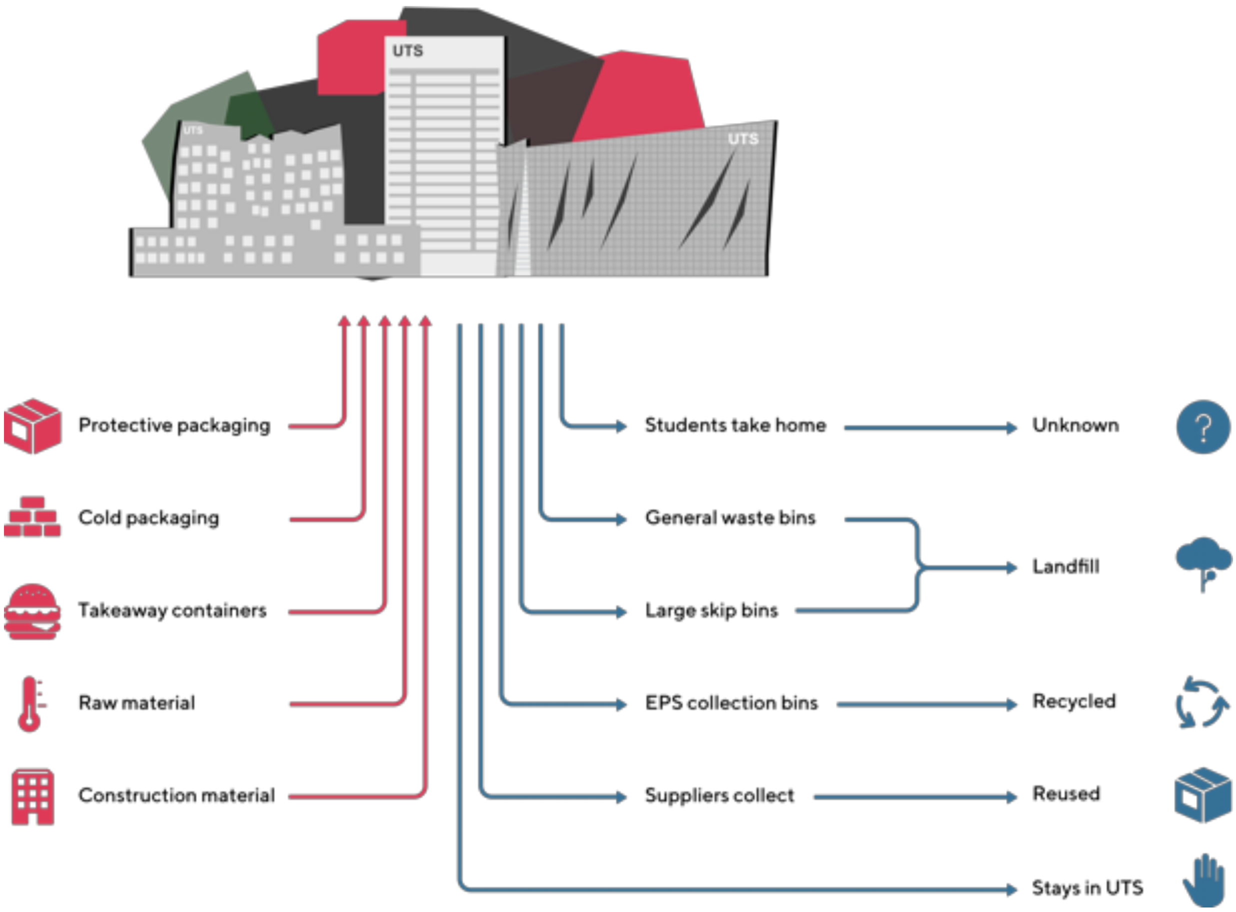


Figure 2: EPS packaging sources by collection point

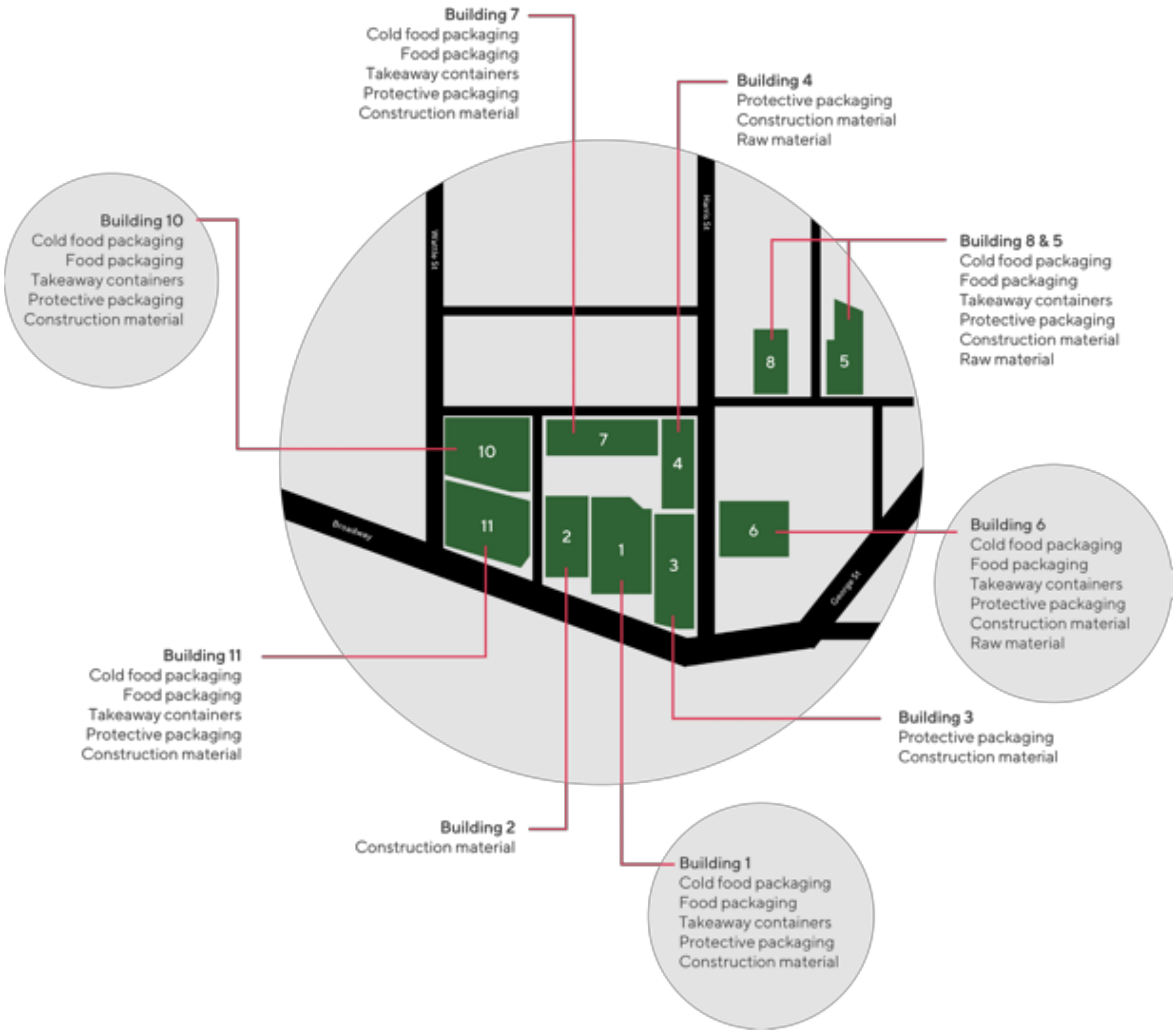


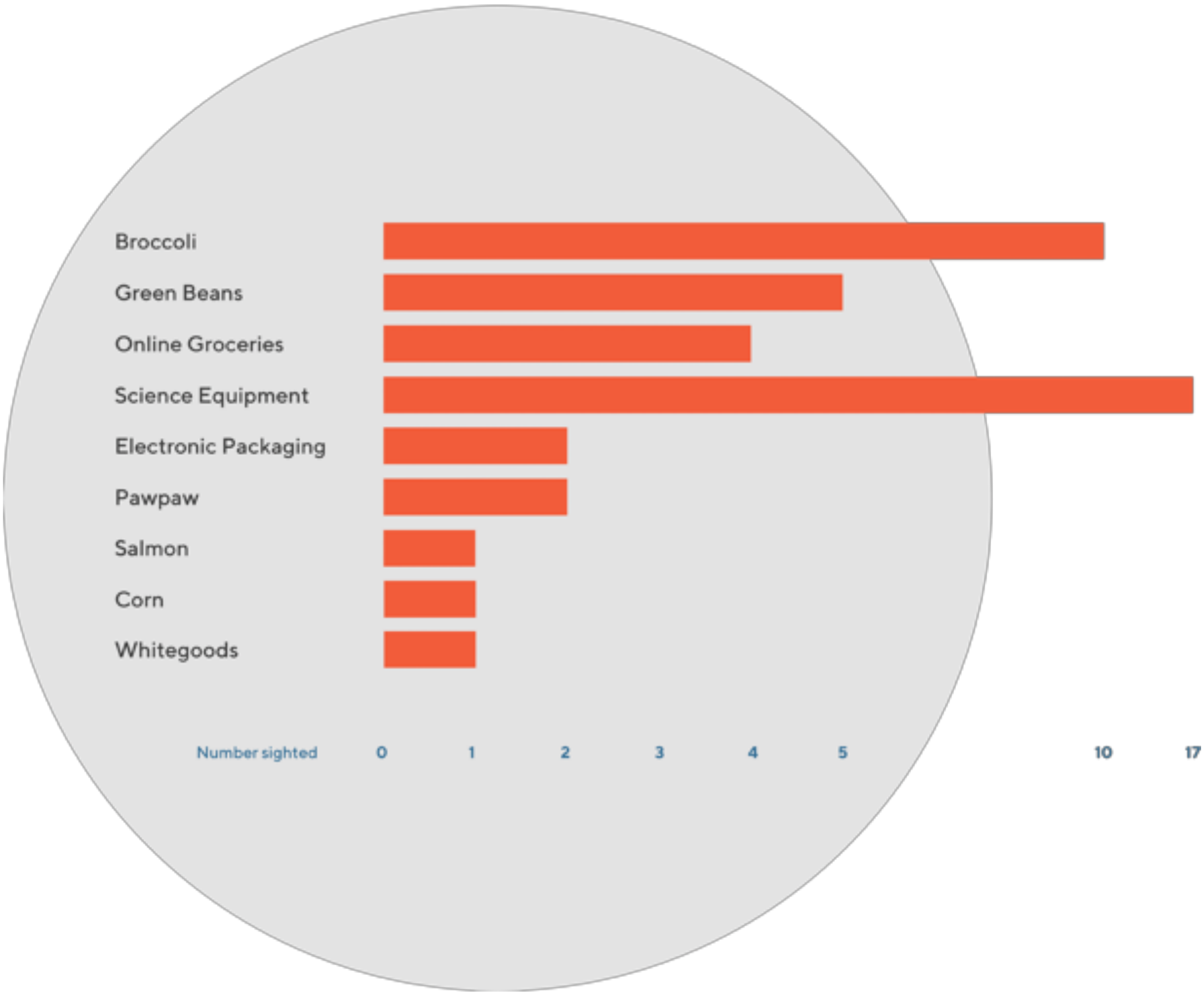
Table 2: EPS packaging sources

Purpose	Source	Product type
Protective packaging		
	All	Ad hoc purchases
	Library	Foam peanuts for books
	Science, Health	Lab equipment
	DAB	Whiteboards
	All	Furniture
	All	Projectors
	All	Whitegoods

	All	Computers
Cold packaging		
	Science	Scientific samples requiring dry ice – e.g. bovine serum, tethered membranes
	Food outlets	Broccoli, Green beans, Papaya, Salmon, Corn
	Student housing	Online groceries

Figure 3: EPS collection points

Figure 4: EPS collection point audit



5.2 Identifying EPS alternatives

Based on the waste hierarchy[4], opportunities to avoid the use of EPS, or replace it with less materially intensive and environmentally damaging materials, should be prioritised over recycling. Our investigation revealed a number of opportunities for removing or replacing sources of EPS within the UTS system, and areas where further investigation of systemic barriers to its removal may be carried out. Alternatives to the key EPS product categories are discussed below.

Protective packaging

All departments surveyed used some form of protective EPS packaging. The majority of packaging was for protecting valuable hardware such as whitegoods, lab equipment, and electronic equipment such as computers. Alternative materials currently in use for protective packaging include corn starch, seaweed, mushroom, and recycled cardboard based materials, in addition to biodegradable air pillows (see Figures 5 & 6). Moreover, companies such as Dell and Apple are beginning to replace EPS with materials such as cardboard, fungi or bamboo.

Given that the majority of EPS in this category that enters the UTS system is protecting goods that are ordered in, replacing EPS accompanied by purchases of hardware and equipment would consequently require embedding EPS avoidance in the university's procurement policies, and encouraging companies to utilise alternatives.

Figure 5: Packaging material from the pith of a fast-growing plant called Soft Rush.

Image source: https://www.donkwaning.com/

Figure 6: IKEA plans to phase out EPS packaging for all flat pack products and replace with a mushroom-based alternative.

Image source: https://www.ikea.com/ms/en_US/pdf/.../IKEA_BEHIND_EPS_free_packaging.pdf

Cold packaging

The key sources of EPS cold packaging surveyed were scientific samples requiring dry ice and foods imported for sale in cafes, including broccoli, green beans, papaya, salmon, corn. UTS has recently prohibited food outlets on campus from selling food in EPS packages, however much of the food ingredients ordered are packaged in EPS. Replacing the thermal properties of EPS presents more of a challenge than replacing EPS for protective packaging in many cases. Products such as Woolcool[5] are providing alternatives for cold storage transport (Figure 7). However, in some cases where new storage materials are not available or applicable, alternatives may have to be sought to different aspects of the provisioning system that necessitate items to be kept cool rather than the product itself. For example, by locally sourcing as much food as possible, requirements for cold storage may decrease. For items that are popular and cannot always be sourced locally, reusable packaging options are available. However, the capacity of UTS to utilise this packaging is restricted by the decisions of produce providers to utilise alternatives. Given this situation, UTS may be in a position to influence the procurement and logistics of particular businesses if the supply contract is substantial enough.

Figure 7: Woolcool insulated packaging for temperature sensitive items, such as pharmaceutical products and chilled and frozen foods.

Image source: https://www.woolcool.com.au/#

5.3 Stakeholder consultation and sustainability assessment

For a closed-loop to be achieved, recycled EPS products had to be carefully selected to ensure that they would remain within the UTS system for as long as possible prior to being recycled again or disposed of. In order to achieve these criteria, the products had to respond to real needs within the UTS community. To determine these needs interviews were conducted with facilities staff, hospitality staff, students, teaching and research staff. These interviews generated a number of product ideas which were then assessed according to a broader sustainability assessment framework, designed to ensure a closed-loop system was achieved (Appendix A). Based on this framework, and considering constraints imposed by the material and digital technologies available, two product types were identified to be prototypes and trialled coffee cup holders and office signage. The assessment for each product based on the sustainability assessment framework is presented in Table 3.

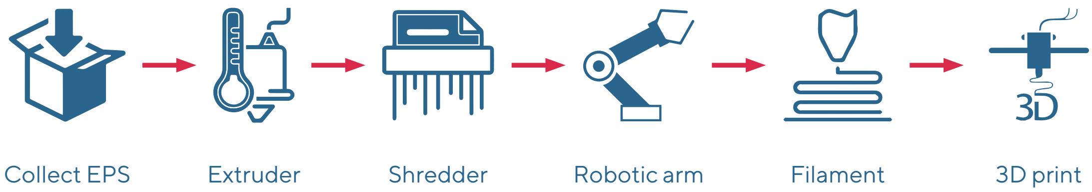
Table 3: Assessment of coffee cup holders and office signage against sustainability assessment framework

	Coffee Cup Holder	Office Signs
How is it made?		
• Requirement for virgin materials	5	5
• Virgin material replacement	5	5
• Amount of EPS required to produce one product	2	3
• Energy required to product	4	4
• Material intensity compared to alternative products	2	4
How is it designed?		
• Demand for product	3	4
• Durability of product	4	3
• Marketability of product	4	4
• Replaces existing product	4	4
• Reparability	1	1
• Packaging requirements	2	4
• Number of times it can be recycled	4	4
• Other potential environmental impacts	3	3
• Probability the product will be recycled	4	4
• Accessibility of necessary recycling infrastructure	3	3
• Ability to upcycle	1	1
How will it be used?		
• Probability of continuous use over time	4	4
• Need for additional operational materials	5	5
• Need for additional operational energy	5	5
• Necessity of product	1	1
• Educational value	5	3
• Probability of increasing waste	3	3
	74	**77**

5.4 Recycling process

Alongside the characterisation of EPS flows within UTS, and the assessment of potential alternatives, technologies for recycling EPS on campus were also explored. The images in Figure 8 illustrate the technologies used in this process. EPS was initially processed using a machine commonly referred to as a Compactor Extruder. This machine shredded, heated and extruded the material into condensed blocks (or patties) of the now raw material, Polystyrene (PS). The patties were then shredded into small pieces using a custom built plastic shredder. The shredded plastic was then used as stock material in a robotic arm to print prototype signage. Some of the PS was also sent off campus to create 3D printer filament and pelletised stock.

Figure 8: Recycling technologies utilised



5.5 Design prototypes: evaluation

Prototype evaluation: office signage

The final prototypes of the office signage designs (Figure 9) were successful as aesthetic and functional replacements for current signage used around the campus. The key elements of the recycling process are represented pictorially in Figure 10. The key barriers for taking this product forward on campus are processing and printing facilities to produce the signage at a scale adequate to the signage needs across campus. Uniformity of style across multiple types is one of requirements of signage on campus. Large batches of signage would need to be produced in order to offer a viable alternative to current signage systems and current facilities would not meet such needs. Current contracts for campus signage are in place with an external organisation. A new signage system would require support from UTS management to alter their current contractual arrangements for office signage.

Figure 9: Final recycled EPS signage prototypes

Figure 10: Recycling EPS for office signage

Collect EPS

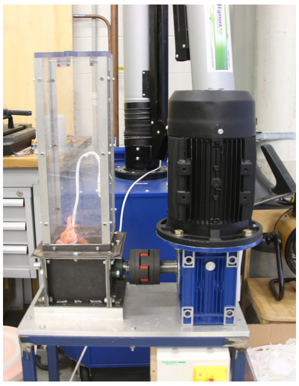
Extruder

Mould

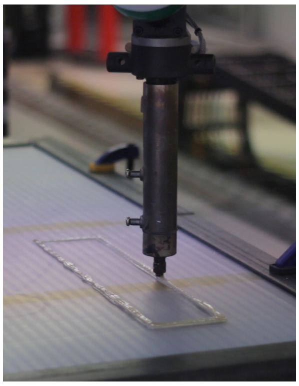
Tests

First and last tests

3 best tests



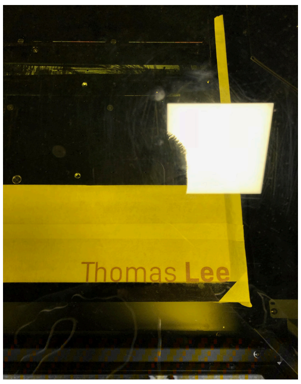
Shredder



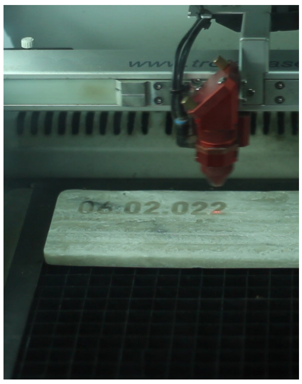
Robotic arm

Results

Milling



UV Print



Laser-cut

Prototype evaluation: coffee cup holder

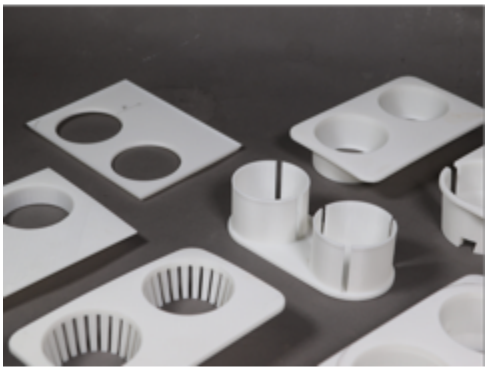
The coffee cup holder was a less resolved prototype than the signage designs, but results were successful enough to suggest that a feasible result could be realised with more time. As the holder requires a more complicated form than the signage, the designs needed to be printed from PS filament in a smaller 3D printer. UTS does not currently have the pelletiser machine required to make the appropriate filament out of EPS for this 3D printer at present, the filament used in this process consequently took some time to procure from an interstate company and there was not enough time or stock to properly complete multiple prototypes. The holders, however, were successfully printed using ABS (Acrylonitrile Butadiene Styrene, a commonly used 3D printing material for design prototypes) and based on the previous PS prototypes. If UTS were to procure a pelletiser, the final prototypes could be produced using EPS.

Figure 11: final coffee cup holder prototype

Figure 12: Developing coffee holder prototypes

Current coffee holders on campus

Exploring additional functionality



Different styles trialled

5.6 Future considerations

Time and access to machinery

In order to produce products made with recycled EPS at even a modest scale the university would need greater processing facilities. While current facilities, for shredding and 3D printing in particular, are sufficient to test design prototypes, greater capacity would be needed.

Filament

The university does not currently have the technology to create 3D printer filament from recycled EPS. However, the technology is not overly expensive and the university is in the process of obtaining an appropriate machine for future experimentation.

Heat extruder fumes

During the research UTS central services resolved to discontinue use of the EPS Compactor Extruder machine and instead have started using a Cold Press Compactor due to work health and safety issues concerning fumes. The Compactor Extruder was used in a poorly ventilated space and the fumes released in the process are toxic and potentially harmful to workers. If the university or a similar organisation wished to invest in extruding technology for recycling EPS, proper planning for ventilation and worker health and safety would need to be undertaken.

Chemical contamination

The application of some chemical additives to EPS in manufacturing, particularly brominated flame retardants, pose significant health hazards if they remain in recycled EPS products. Exposure to these chemicals through skin contact or ingestion should be avoided. Although flame retardants are primary used in EPS intended for building insulation, there are indications that they may also be present in EPS packaging.[6] Further research is required to determine the extent and types of EPS products (i.e. packaging) that have had chemical additives applied. If flame retardants are present, recycling will require the EPS to be dissolved and separated from the flame retardants prior to reprocessing.

6 Conclusions and next steps

This project demonstrated that EPS collected within UTS can be reprocessed on campus into items that are beneficial to the UTS community. If issues associated with the procurement of additional machinery, ventilation and chemical contamination can be addressed we propose that it is feasible to recycle campus-sourced EPS into essential products, such as signage, trollies, and trays for use in the University.

We have also identified opportunities to replace EPS with more sustainable packaging options, which should be prioritised over the implementation of any recycling mechanisms. This will require an adjustment in procurement policies and an assessment of the range of impacts associated with alternatives. In cases of temperature sensitive materials, this will likely require a re-evaluation of broader systems of distribution and provisioning.

6.1 System scale-up: developing precinct-scale EPS recycling

For the system tested in this feasibility study to be scaled-up and made accessible to other organisations within the City of Sydney through networks such as the Better Buildings Partnership a number of steps must be taken:

Material assessment

Basic chemical testing should be conducted on a sample of EPS materials collected on campus to determine whether there are chemical contaminants present.

Further experimentation with the capacity of recycled EPS products to be recycled numerous times, and into a greater diversity of products, will also be required.

Engaging organisations within City of Sydney

To extend this closed loop system to encompass other organisations within the City of Sydney consultation with interested participants is required to answer the following questions:

1. What are the current flows of EPS within organisations within the City (including consumption rates and sources)?
2. Can EPS be feasibly replaced as a packaging material for any of the existing products procured?
3. Are there existing modes of transport (e.g. reverse logistics) that could transport the EPS from organisations to UTS?
4. What types of recycled EPS products wold be beneficial to other organisations within the City (that meet the sustainability assessment criteria)?

6.2 Further opportunities

Recycled EPS in construction

The project identified further opportunities for growing local end markets for building insulation products and waffle pods. UTS could work as a potential aggregation point for EPS in partnership with organisations such as Expanded Polystyrene Australia to develop this option.

This pathway faces additional logistics challenges owing to the requirement that the EPS is not compacted and demonstration of this option is so far limited to closed-loop solutions in the building sector. The tracing of EPS on campus in this project is a first important step towards exploring the potential to provide EPS to the building sector as part of an integrated approach to scaling up EPS management solutions on campus

Exploring options for EPS phase out

The Ellen MaCarthur Foundation in their 2017 report *The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action*[7] presented at the World Economic Forum proposed a global phase out of problematic packaging materials including EPS, along with PS and Polyvinylchloride (PVC). In line with these global efforts to find alternatives to EPS, further research into how the functional affordances of EPS can be met in places like universities with alternative products or services would benefit from concerted effort. Research is required into new material alternatives, in addition to service design opportunities to address broader aspects of the provisioning and consumption systems in which EPS is currently necessary.

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Appendix A: Sustainability assessment framework

Potential recycled EPS products were assessed using the following assessment questions. Answers were provided in the form of a number between 1 – 5, with 1 being least desirable and 5 being most desirable based on probability of contributing to a closed-loop system. The higher the overall score the more desirable the product, with the highest possible score being 110.

How is it made?
- Requirement for virgin materials
- Virgin material replacement
- Amount of EPS required to produce one product
- Energy required to product
- Material intensity compared to alternative products

How is it designed?
- Demand for product
- Durability of product
- Marketability of product
- Replaces existing product
- Reparability
- Packaging requirements
- Number of times it can be recycled
- Other potential environmental impacts
- Probability the product will be recycled
- Accessibility of necessary recycling infrastructure
- Ability to upcycle

How will it be used?
- Probability of continuous use over time
- Need for additional operational materials
- Need for additional operational energy
- Necessity of product
- Educational value
- Probability of increasing waste